8-1909

Bulletin No. 105 - Factors Influencing Evaporation and Transpiration

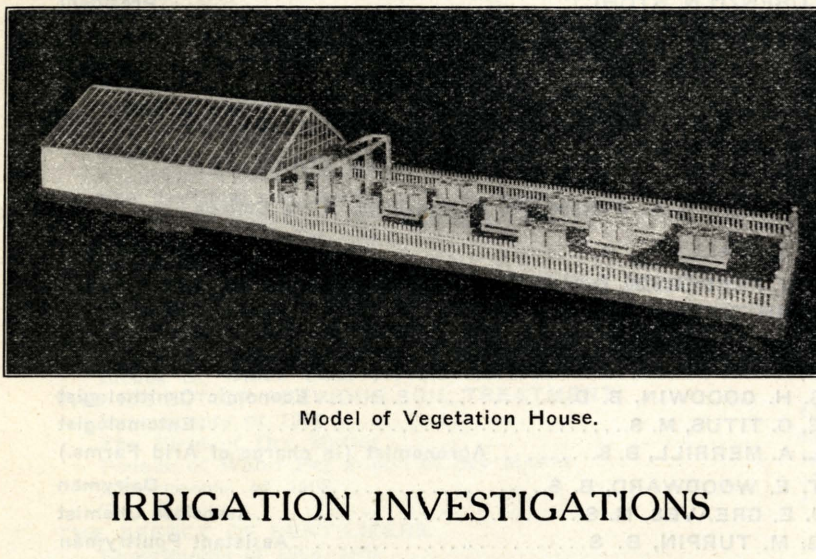
John A. Widtsoe

Irrigation

Utah Agricultural College

EXPERIMENT STATION

Bulletin No. 105



Model of Vegetation House.

IRRIGATION INVESTIGATIONS

Factors Influencing Evaporation and Transpiration

BY

JOHN A. WIDTSOE

LOGAN, UTAH, AUGUST, 1909

SKELTON PUBLISHING COMPANY
SALT LAKE CITY, UTAH

The Utah Agricultural Experiment Station

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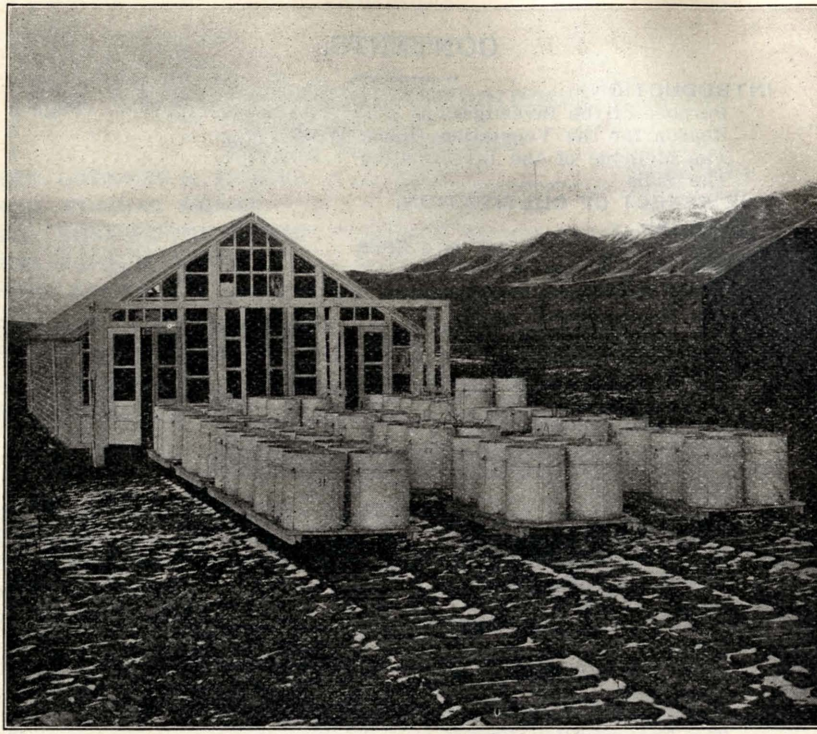

Fig. 1.—Vegetation House and Pots.
(In Winter.)

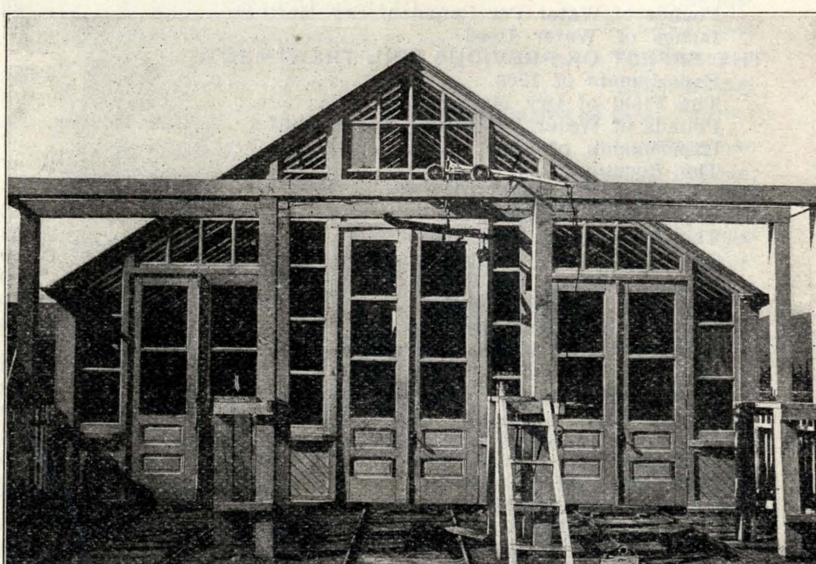

Fig. 2.—Front of Vegetation House.
(Showing Weighing Device and Tracks.)

INTRODUCTION.

Purpose of the Investigation.

The irrigation investigations conducted by the Utah Experiment Station, some of the results of which form this *report, were undertaken for the purpose of adding to our knowledge of the natural laws upon which the art of irrigation may be safely built. The work has had for its direct object the study of the mutual relations of plants, soils and water, as these relations may indicate the most economic use of water for plant production. In pursuit of the investigations it became necessary not only to follow the movement of water in soils under irrigation conditions, but to determine also the relative amounts of water evaporated directly from the soil and taken from the soil by plants. Of equal importance became also, the determination of the optimum and minimum amounts of water for the profitable production of vegetable organic matter. Considering the needs of the practical farmer, three great questions continually presented themselves to the investigators: (1) To what extent is it possible to regulate the amount of water that evaporates directly from the soil? (2) Is it possible to regulate the amount of water taken from the soil by plants? and (3) Is it possible to prevent loss of water by seepage? To answer these questions a host of secondary problems arose, such as the effect of cultivation on soil water evaporation, the methods of irrigation for the most effective use of water, the effect of available plant foods on transpiration, the effect of shade on the direct evaporation from the soil, and so on.

Briefly, however, the real purpose of these investigations has been and is the determination of the conditions under which

*Earlier reports are found in Bulletins 80, 86, and 104. Several other reports are in course of preparation.

a maximum amount of vegetable substance of best quality may be produced with a minimum amount of water, having in view the actual conditions existing on the farms of the irrigated sections.

Reason for the Vegetation House Work.

The experimental irrigation field is situated about two miles north of the College Campus. It possesses unusually uniform soils and is in other ways admirably adapted to investigations of this kind. The field was divided into a large number of plats of uniform size (29 ft. x 57 ft.) and supplied with an elaborate system of flumes and weirs, whereby accurately measured amounts of water could be applied at any time to any of the plats.

The attempt was made to eliminate all variable factors that would render comparisons uncertain, but the occasional rains during the summer months and the downward movement of the soil water, were largely beyond the control of the experimenters. There were also times when heavy canyon winds introduced uncontrollable conditions over the experimental field. Of these variable, uncontrollable conditions, however, the most serious was the downward movement of the irrigation water. It has been explained in Bulletin 104 that the water applied to soils, whether in the form of rain, or snow, or irrigation water, passes far below the limit of the 8 foot augers used in these investigations for the purpose of following the downward movements of soil water.

One purpose of the vegetation house work herein discussed was to grow plants under controlled conditions, which, especially, would not permit any loss of water by downward percolation. Another purpose, of equal importance, was the comparison of various types of soil for irrigation practices. Representative soils were shipped in from various parts of the State and compared with respect to their water and crop requirements. In fact, the vegetation house experiments were carried on very largely to determine to what extent the laws discovered on the experimental field would hold with other soils found in the arid region.

The Methods of the Investigation.

The method of carrying on the work herein described was to grow plants in pots filled with known weights of different soils and to which definite amounts of water were applied. The pots were made of heavy galvanized iron. They are 2½ feet

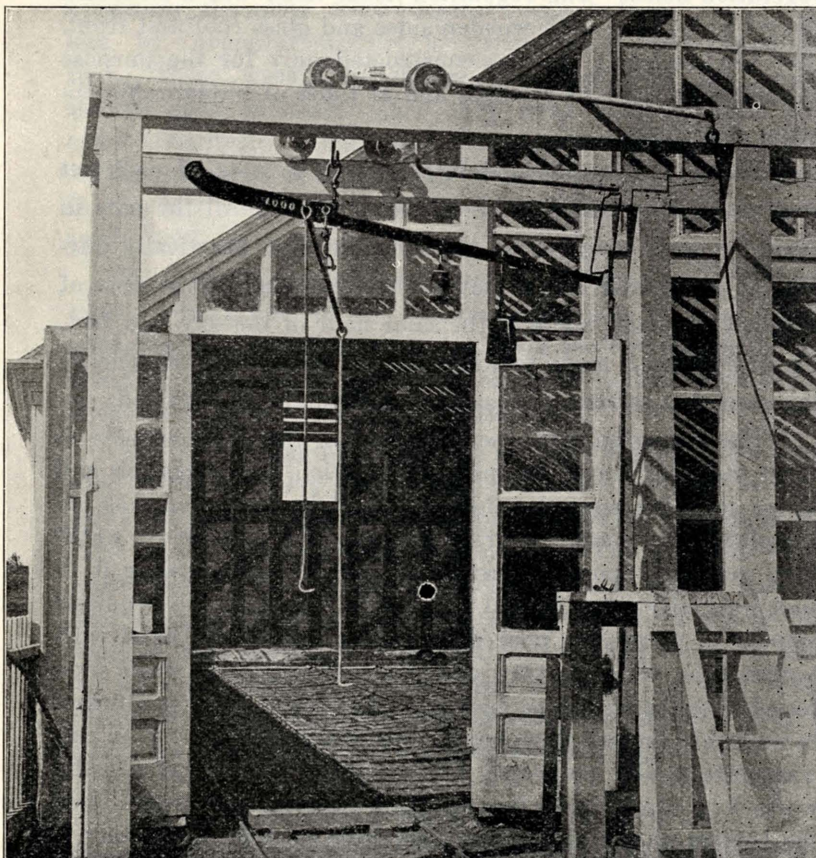

Fig. 3.—Weighing Device.

high and 2 feet in diameter. One ring of heavy band iron about 6 inches from the top supports two iron bands, crossed under the pots and bent up along the sides. Two ends of one of these strips are bent into ears by which the pots can be swung from the cars and weighed. The pots were placed in groups of six on low trucks or cars, similar to those used in brickmaking establishments. The cars carrying the pots were wheeled into the vegetation house every evening at nightfall and were wheeled out the next morning at sunrise. In times of rain, or canyon winds, the pots were also wheeled into the vegetation house. The vegetation house itself was a structure 26 feet by 54 feet, with wooden sides and glass roof and front. (See illustrations.) It was constructed only for the purpose of sheltering the pots at night and at times of unfavorable climatic conditions.

The pots were divided into sets. The pots of each set were treated as nearly alike as was possible. All the pots in every set were irrigated on the same day and practically during the same hour of the day. The weighings of the pots of each set were also made at the same hour of the day. In fact, the attempt was made to weigh all the pots in all the sets on the same day so that comparative data might be obtained.

The irrigation water was applied in the different sets in three different ways: by surface irrigation, sub-irrigation and water standing near the surface. Surface irrigation was accomplished by simply pouring the required amount of water very carefully upon the surface of the soil and allowing it to sink naturally into the soil. For sub-irrigation, the requisite amount of water was poured through a funnel connected with a glass tube, which in turn was attached to a small waste pipe found near the bottom of each pot; thus the water was allowed to soak into the soil from below. For standing water, a tin can was permanently connected with the small waste pipe and the water kept standing in this can at a distance of 6 inches from the bottom of the pot, or two feet from its top. From day to day, water was added to this covered can to supply the water which had soaked into the soil. Of course, a record was kept of the amount of water thus added. All the sets contained duplicate series of pots—one bare and the other cropped. This was done for the purpose of determining, approximately at least, the amount of water that actually passed through the plant. The difference between the amount lost from the bare pot and the amount lost from the corresponding cropped pot could, in most cases, be justly charged to transpiration.

All pots were weighed just before each irrigation and then immediately brought up by the addition of water to a definite weight representing a definite percentage of water in the soil (on the basis of dry soil). Every seven days after irrigation the pots were again weighed to determine the loss by evaporation, or by evaporation and transpiration. These weekly weighings continued until the plants showed need of water, when they were weighed again and again irrigated. It may be remarked that this method permitted the plants in all the sets to use the maximum of water. In this last respect, the conditions were different from those on the field.

The weighing device consisted of a large steel-yard, accurate with a load of one thousand pounds to one pound, swinging from the short arm of another lever by which the pot could be swung from the car on which it rested. The device is shown in some detail in the illustrations.

The pots belonging to any one set were seeded at the same time on the same day on soils that previously had been brought up to the same degree of saturation. Likewise, all pots of the same set were harvested on the same day. The harvested crops were taken to the laboratory where the total weight and per cent. of moisture were immediately determined. Later on, the samples were subjected to other analyses. The total dry matter recorded in the following pages refers to the part of the plant above ground, with the exception of sugar beets, in which the roots and the leaves were weighed together.

The Soils.

Four soils were used in these investigations: 1, College loam; 2, clay; 3, sand and 4, Sanpete clay. The College loam was taken from the experimental farm just east of the College campus. The clay was taken from a clay bank not far from the College. The sand was taken from a sand deposit made by Logan River about a half mile from the College campus. The Sanpete clay was shipped from a field about a mile and a half north of Manti, Sanpete County, Utah. The Sanpete clay represents a large portion of the fertile Sanpete Valley of Utah.

Table No. 1.

CHEMICAL ANALYSIS OF SOILS FROM VEGETATION HOUSE.

(In Per cents.)

Constituent.	COLLEGE LOAM	CLAY	SAND	SANPETE CLAY
Insoluble Matter.......	66.69	46.09	51.055	55.41
Potash (K^2O).........	0.549	0.646	0.149	1.134
Soda (Na^2O).........	0.485	0.402	0.212	.876
Lime (CaO)..........	7.414	19.53	17.43	11.74
Magnesia (MgO)......	4.147	4.566	5.631	3.811
Manganese Oxide (MnO)	None.	None.	None.	None.
Ferric Oxide (Fe^2O^3).	2.926	2.843	0.875	3.954
Alumina (Al^2O^3)......	3.494	3.722	1.251	5.847
Phos. pentoxide (P^2O^5)	0.252	0.20	0.143	0.242
Sulphur trioxide (SO^3)	0.0748	0.0715	0.0309	0.0751
Carbon dioxide (CO^2).	7.619	18.05	20.725	10.14
Water	2.14	1.56	.195	1.795
Humus	2.176	1.154	0.227	1.289
Total Nitrogen........	0.134	0.0476	0.0191	0.103
Volatile Matter.......		Undetermined.		

Unfortunately, the samples of clay and sand were taken from such depths and locations as to make them extremely infertile and, therefore, not in reality agricultural soils to be compared with the College loam and Sanpete clay. As will be observed in the following pages, this difference in fertility, however, revealed certain laws that might otherwise have been overlooked.

These soils were subjected to chemical analysis after digestion with acid according to the methods of the Official Agricultural Chemists. (See Table 1.) The most striking thing about these soils appear to be the very high content of lime. The clay and the sand contain the largest per cent. of lime. The sand soil in fact is largely a limestone sand. In the essential plant foods the soils do not vary much from the typical soils of the Great Basin. In the Sanpete clay the potash is somewhat higher than the average and in the loam and clay it

Table No. 2.

RESULTS OF PHYSICAL ANALYSIS OF SOILS FROM VEGETATION HOUSE.

(In Per cents.)

Constituent.	COLLEGE LOAM	CLAY	SAND	SANPETE CLAY
Coarse Sand.........	17.69	3.34	70.49	8.68
Fine Sand...........	37.39	14.62	20.75	24.02
Coarse Silt...........	15.19	24.58	3.32	17.47
Medium Silt........	10.36	17.31	1.54	18.05
Fine Silt.............	10.32	9.90	.81	7.77
Clay	9.03	25.84	2.16	18.98
Total............	99.98	95.59	99.07	94.97
Water Soluble.......	0.2397	0.1189	0.1062	0.2689
Apparent Specific Gravity	1.319	1.292	1.319	1.306
Real Specific Gravity.	2.64	2.64	2.81	2.66
Baking Tendency....	842	3214	241	1687
Stickiness	279	541	37	379

Sizes of soil grains: Coarse sand, 1 m. m. in diameter. Fine sand, between .0316 m. m. and 1 m. m. in diameter. Coarse silt, .01 m. m. to .0316 m. m. in diameter. Medium silt, .00316 m. m. to .01 m. m. in diameter. Fine silt, .001 m. m to .00316 m. m. in diameter.

is a trifle lower. The sand is characterized by a much smaller per cent. of potash than is usually found in Utah soils. The soda in the Sanpete clay is so high as to indicate definitely the occurrence of alkali. The phosphoric acid is above the normal in all the soils. The nitrogen in the College loam and Sanpete clay is about that of the average Utah soils, while in the clay and sand it is comparatively low and would, in a measure, account for the low fertility of these soils. The sand is extremely poor in humus.

The soils were also subjected to mechanical analysis with the results appearing in Table 2. The physical analyses justify the names given to these soils. The clay is distinctly a clayey soil and the sand, likewise, is distinctly a sandy soil, containing 70.49 per cent. of coarse sand. The College loam approaches a sandy character, whereas the Sanpete clay is more distinctly of a clayey nature. The per cent. of water soluble material in these soils is a good index to their fertility. The College loam and Sanpete clay average about one-fourth of one per cent. of water soluble material, which probably includes all the immediately available fertility; while the clay and sand contain somewhat less than one-half of that amount. The real specific gravity is practically the same for the four soil samples, though the sand is a little higher. The relative breaking qualities show the degree to which the soils tend to crust on the surface. The Sanpete clay and clay are very much higher in this property than either the loam or the sand, though the loam has more than three times the tendency of the sand. In stickiness also, the clay stands first, while the loam and the Sanpete clay are not very far removed from each other; the sand stands last and is low.

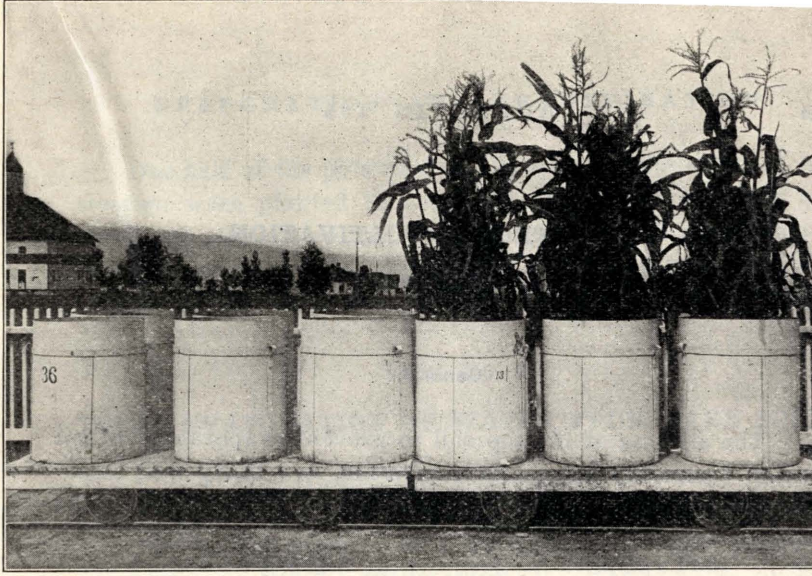

Fig. 4.—Corn in Cultivation Experiments.
(Note the duplicate series of Cropped and Bare Pots.)

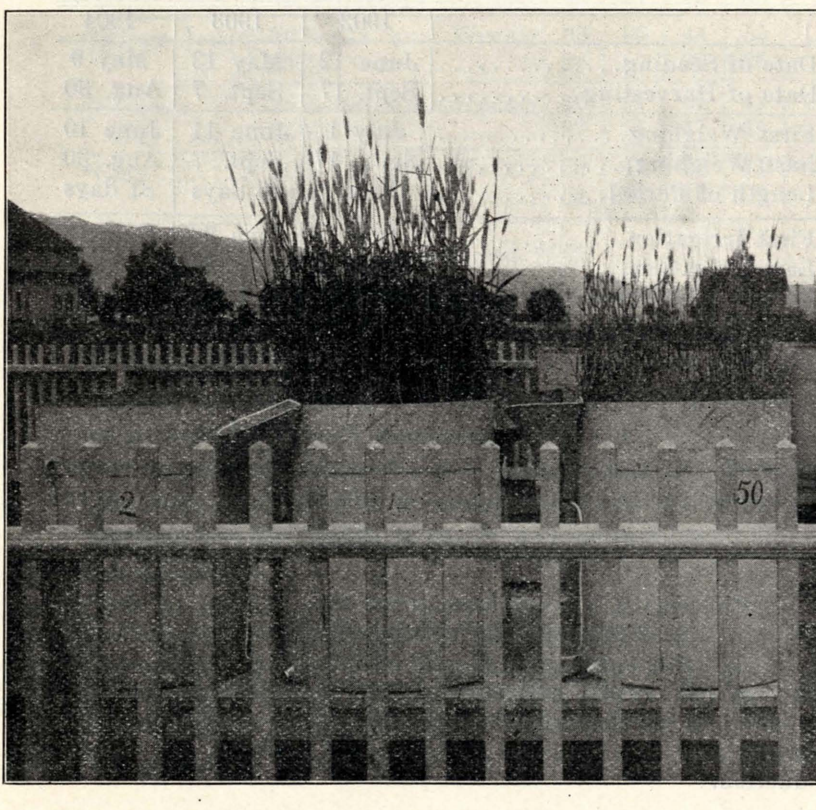

Fig. 5.—Wheat in Sub-Irrigation Experiments.
(Note Funnels for Applying Water at Bottom of Pots.)

THE EFFECT OF CULTIVATION.

(Tillage.)

General.

The stirring of the top soil to prevent evaporation of soil water, commonly known as cultivation, is a fairly well established practice throughout the arid West. However, since the doctrine of the conservation of soil moisture by cultivation rests largely upon the experimental results obtained in countries of abundant rainfall, it was thought advisable to include in the irrigation investigations of this Station a study of the value of cultivation as a means of conserving soil moisture.

Table No. 3.

HISTORY OF POTS IN CULTIVATION EXPERIMENTS.

	1902	1903	1904
Date of Seeding.............	June 12	May 13	May 9
Date of Harvesting...........	Sept. 17	Sept. 7	Aug. 30
First Weighing...............	July 1	June 11	June 10
Last Weighing................	Sept. 17	Sept. 7	Aug. 30
Length of Period.............	79 days	88 days	81 days
First Irrigation...............	July 1	June 26	June 13
Last Irrigation...............	Sept. 1	Aug. 20	Aug. 2
Length of Irrigation Period...	63 days	55 days	50 days
Number of Irrigations.......	6	5	4

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*Cultivation is used throughout this bulletin to indicate the stirring of the top soil, usually after the crops have been planted. **Non-cultivation** is used to indicate the failure to stir the top soil. These words are used in preference to the words tillage and uncultivation, that frequently occur in agricultural literature, but mean more generally the processes of crop production.

One-half of the pots used in the study of the effect of cultivation were planted to corn and the other half were left bare. At each irrigation the sand was brought up to 15 per cent. of water; the College loam to 20 per cent.; the Sanpete clay to 25 per cent. and the clay to 30 per cent. of water,

Table No. 4.

TOTAL EVAPORATION OF WATER FROM BARE SOILS.

(Cultivation Experiments.)

SOIL	Degree of Saturation	CULTIVATION	Loss in Pounds per Square Foot				Saved by Cultiva'n
			1902	1903	1904	AV'GE	
Sand	15%	48 hrs. Weekly	46	76	36	53	34%
	15%	None.........	65	121	55	80	
College Loam	20%	48 hrs. Weekly	35	86	44	55	Loss
	20%	None	24	58	25	36	
†Sanpete	25%	48 hrs. Weekly	32	57	37	42	13%
Clay	25%	None	27	71	47	48	
*Clay	30%	48 hrs. Weekly	59	41	23	41	63%
	30%	None	54	156	116	109	

*Saturation of Clay in 1902 was 25%.

†Saturation of Sanpete Clay in 1902 was 20%.

on the basis of dry soil. Table No. 3 shows the times of planting and harvesting and also the duration of the growing and irrigation seasons.

At definitely stated times after each irrigation, half of the pots were cultivated to a depth of one inch by means of a gardener's comb; the surfaces of the corresponding half were left untouched.

The Evaporation From Bare Soils.

Table No. 4 shows the evaporation from the bare soils, during three years, with and without cultivation. The soil was stirred on the cultivated pots, in every case, 48 hours after irrigation and then weekly. The beneficial effect of cultivation was strikingly marked on all of the soils with the exception of the College loam which was not at all benefited. Cultivation reduced evaporation from the clay 62.5 per cent.; from the sand 34.1 per cent. and from the Sanpete clay 13 per cent. These results confirm the results of former experiments and justify the systematic and careful cultivation that the wise farmers of the arid West give to their soils.

Table No. 5.

YIELD OF DRY MATTER. (CORN.)

(Cultivation Experiments.)

SOIL	Degree of Saturation	Cultivation	Yield in Grams per Pot 1902	1903	1904	AV'GE	Increase by Cultivation
Sand........	15%	48 hrs. Weekly	55	58	40	51	Loss
	15%	None.........	65	66	70	67	
College Loam	20%	48 hrs. Weekly	331	730	285	449	14%
	20%	None.........	308	699	156	388	
Sanpete Clay	25%	48 hrs. Weekly	289	541	229	353	5%
	25%	None.........	363	434	210	336	
Clay........	30%	48 hrs. Weekly	109		113	111	31%
	30%	None........	70	135	83	77	2 yrs.

Such results, applied to actual farm practice and expressed in terms of acre feet of water, teach that by proper soil cultivation, the present water supply may be made to cover nearly one-third more land than would be the case if careless soil cultivation is practiced.

The results obtained on the College loam, however, are wholly different from those expected. Since the work was done carefully, and is corroborated by other tests (page 22), the loss resulting from cultivation can not be charged to exprimental error. If any error exists, it must lie with the method of cultivation. There are undoubtedly many Western soils which, if cultivated for the conservation of soil moisture, must be stirred deeply in order to secure beneficial results.

Even on this soil, however, while cultivation did not save moisture it had other beneficial effects. The lesson of this experiment is that, to prevent direct evaporation of water from the soil, systematic cultivation should be practiced on all irrigated lands.

The Yield of Dry Matter.

On all the soils, excepting the sand, cultivation increased the yields of dry matter from the cropped pots. (See Table No. 5.) The increase due to cultivation is surprisingly high: on the clay it was nearly 31 per cent.; on the College loam and Sanpete clay it was nearly 5 and 14 per cent., respectively. Certainly, such increased crop yields fully compensate the farmer for the labor of cultivation.

It is not easy to understand why cultivation should diminish the yield from the sandy soil. However, it must not be forgotten that the sand and clay soils used in these experiments were not agricultural soils, but, unfortunately, were taken from inert sand and clay deposits. The total yields of dry matter from both the sand and the clay were far below those normally obtained from somewhat infertile agricultural soils. All data, therefore, dealing with the production of dry matter on the sand and clay soils used in these experiments should be accepted with considerable caution. However, the indication is clear from Table No. 5 that cultivation on the loose, coarse sand was not nearly so beneficial, considering the production of dry matter, as on the heavier soils.

The lesson of Table No. 5, however, is very plain. Cultivation not only tends to conserve soil moisture, but increases definitely and to a large extent the dry matter produced.

Water Per Pound of Dry Matter.

Are the increased yields of dry matter on the well cultivated soils due to the conserved soil moisture or due to other factors? This question is practically answered in Tables No. 6 and 7 which show the total number of pounds of water lost by evaporation from the soil and by transpiration from the plants for each pound of dry matter produced.

From the sand soils no reliable data concerning the relation of cultivation to the water cost of the dry matter can be gathered. The reason for this appears to be that the ease with

Table No. 6.

EVAPORATION AND TRANSPIRATION. (CORN.)

(Cultivation Experiments.)

SOIL	Degree of Saturation	Cultivation	Lbs. of Water for One Lb. of Dry Matter 1902	1903	1904	Average
Sand	15%	48 hrs. Weekly	1932	1993	1939	1954
	15%	None.	1862	2585	1136	1861
College Loam	20%	48 hrs. Weekly	444	389	437	423
	20%	None	634	496	1133	754
Sanpete Clay.	25%	48 hrs. Weekly	661	537	844	681
	25%	None	544	802	888	744
Clay	30%	48 hrs. Weekly	1348		2021	1684
	30%	None	1833	(2117)	2195	2019

which water evaporates from sand surfaces (See Table No. 4) and the strong effect of shade on evaporation (See Table No. 12) and the infertility of the sand, discussed in the preceding section, combine to introduce variable conditions beyond the easy control of the experimenters. Practically the same difficulties connect themselves with the clay, though the results as shown in Table No. 6 are concordant.

The College loam and the Sanpete clay, however, which are truly agricultural soils, show very definite results. In all but one of the six cases, fewer pounds of water were evaporated and transpired on the cultivated pots for the production of a pound of dry matter than on the non-cultivated pots. This suggests that there may be some other beneficial effect besides the simple saving of soil water resulting from cultivation, and which enables plants to produce dry matter with less water than is possible on non-cultivated pots.

The Transpiration Factor.

On well cultivated soils does less water actually pass through the plant for each pound of dry matter produced? That is, is the transpiration factor lower? Table No. 7 has been constructed to answer this question.

Table No. 7.

TRANSPIRATION. (CORN.)

(Cultivation Experiments.)

SOIL	Degree of Saturation	Cultivation	Lbs. of Water for One Lb. of Dry Matter 1902	1903	1904	Average
Sand	15%	48 hrs. Weekly	732	(281)	(411)	732
	15%	None	454			454
College Loam	20%	74 hrs. Weekly	295	236	225	252
	20%	None	523	378	908	603
Sanpete Clay.	25%	48 hrs. Weekly	280	388	615	428
	25%	None	439	569	595	535
Clay	30%	48 hrs. Weekly	582			582
	30%	None	753	(468)		753

The transpiration values of Table No. 7 were obtained by subtracting from the total amount of water lost from a pot on which corn was growing, the amount of water lost from a corresponding bare pot placed under like conditions. While it cannot be said with certainty that the evaporation of water from the soil surface of a pot on which plants grow is precisely the same as from the soil surface of a bare pot placed under like conditions, yet it must be approximately the same. Owing to the shadow cast by the plant, the evaporation of water from the soil surface of a cropped pot is undoubtedly somewhat less than from the soil surface of a corresponding bare pot. This method of determining transpiration tends, therefore, to give transpiration factors that are somewhat too small. However, while the absolute accuracy of the transpiration data may be questioned, their relative value, which, alone, is considered in this bulletin, may be accepted as being practically correct. Work of this kind presents great experimental difficulties and it is questionable if any other method known at the present time would give more nearly exact results than the method here applied.

The College loam and Sanpete clay show, with only one exception, that on the cultivated soils fewer pounds of water were required to pass through the plant for the production of one pound of dry matter than on the non-cultivated soils. On the College loam there was a saving due to cultivation of 58 per cent., and on the Sanpete clay of 20 per cent. The results for the clay are complete for only one season, but show the value of cultivation in reducing the transpiration factor.

It may be fairly concluded from these results that cultivation not only prevents direct evaporation of water from the soil, but also reduces materially the amount of water that must be transpired by a plant for the production of a certain definite quantity of dry matter. While a full explanation of this behavior can not now be made, yet it may be suggested that the freer circulation of air in the cultivated soils helps to set free plant food, and that there are many reasons for believing that the amount of water required by a plant for the production of one pound of dry matter is less on fertile soils than on infertile ones. This may in part be gathered from the larger transpiration figures for the infertile sand and clay soils.

Whatever the final explanation may be, this phenomenon emphasizes even more than before the importance of the careful and thorough tillage of the soil. The advantage of cultivation is two-fold: it reduces the direct evaporation of water from soil surfaces and it diminishes the transpiration factor.

The Ratio Between Evaporation and Transpiration.

In Table No. 8, the data discussed in the preceding tables have been arranged to show the per cent. of the total loss of water due to transpiration. While far-reaching conclusions can not be drawn from the available data, yet it seems that on the College loam and Sanpete clay considerably more than one-half, and on the sand and clay, considerably less than one-half, of the total loss of water is chargeable to transpiration.

Table No. 8.

RATIO BETWEEN TRANSPIRATION AND TOTAL LOSS OF WATER.

(Corn.)

		Per Cent. of Total Loss due to Transpiration			
		1902	1903	1904	Average
Sand	Cultivation	38	(14)	(21)	38
	None	25			25
College Loam	Cultivation	67	57	50	58
	None	82	73	82	79
Sanpete Clay	Cultivation	73	59	72	68
	None	64	81	71	72
Clay	Cultivation	43			43
	None	41	(22)		41

Inches of Water Used.

Table No. 9 has been constructed simply for the sake of comparison. It shows the inch equivalents of the total water lost from the pots in the cultivation experiments. It must be remembered that maximum results only were obtained in the vegetation house, for whenever any plant seemed to be suffering for water, all the pots in the set were irrigated to the requisite degree of saturation. Even under these maximum conditions it may be observed from Table No. 9 that the largest amount of water used on a cropped soil was not quite 33 inches. This is especially interesting in view of the fact that on many of our farms, the soils of which have stored much of the winter precipitation, are used annually from 20 to 40 inches of irrigation water.

The Evaporation From Bare College Loam.

It was noted in Section 6 that cultivation of the College loam increased the evaporation of soil water. This unexpected behavior was subjected to further tests on a number of pots during the years 1902 and 1903. Cultivation was performed on these pots by six different methods. The results from the bare pots are shown in Table No. 10. During both years and in every case the amounts of water evaporated from the non-cultivated pots were smaller than the amounts evaporated from any of the other pots. This is in strict confirmation of the results alrady discussed. (See p. 16.)

Table No. 9.

INCHES* OF WATER USED. (CORN.)

(Cultivation Experiments.)

SOIL	Degree of Saturation	Cultivation	Av. No. of Inches of Water Used 1902-04	
			Bare	Cropped
Sand	15%	48 hrs. Weekly........	10	13
	15%	None	15	17
College Loam	20%	48 hrs. Weekly........	11	25
	20%	None	7	32
Sanpete Clay.	25%	48 hrs. Weekly........	8	31
	25%	None	9	33
Clay	30%	48 hrs. Weekly........	8	29
	30%	None	21	27

*Inches means the depth, above the soil surface, to which the water would stand had it been applied at one time.

While the anomalous behavior of the College loam can not now be explained, yet it is unquestionably true that the tillage of this soil to a depth of one inch does not conserve soil moisture. It may be that a deeper or a different method of cultivation would have resulted differently. It may be remarked that the College loam does not crust hard, but forms a thin, easily broken crust after irrigation. This peculiar behavior of the College loam indicates the necessity for studying different soils for the purpose of discovering the methods of cultivation whereby the desired saving of soil moisture may be accomplished. It is worthy of note that Table No. 10 teaches that cultivation is most effective when it is performed very soon after irrigation.

Cropped College Loam.

In Table No. 11 are found the yields of dry matter and the evaporation and transpiration factors of the cropped pots corresponding to those of Table No. 10. With one exception, the pot that received no cultivation produced the smallest amount of dry matter. The largest number of pounds of total water

TABLE NO. 10.

EVAPORATION FROM BARE COLLEGE LOAM SOIL.

(Cultivation Experiments.)

(20% Saturation.)

Cultivation	Loss in Pounds per Square Foot		
	1902	1903	Average
24 hours Weekly..........	27	61	44
28 hours Weekly..........	38	86	62
72 hours Weekly..........	36	82	59
One week Weekly.........	35	81	58
48 hours, twice Weekly....	34	62	48
None	24	58	41

for the production of one pound of dry matter was in every case required by the pot which received no cultivation. Likewise, the number of pounds of water that actually passed through the plants for every pound of dry matter produced was lowest on the pots that had been cultivated. In fact, the amount of water required to produce one pound of dry matter was reduced between 17 and 41 per cent. as a direct result of the stirring of the top soil. In all particulars then, the results obtained in the special study of the College loam confirm the conclusions already drawn from the first cultivation experiments.

Table No. 11.

CORN ON COLLEGE LOAM.

(Evaporation Experiments—20% Saturation.)

CULTIVATION	Yields of Dry Matter Grams per Pot			Pounds Water for One Pound Dry Matter: Evaporation and Transpiration			Pounds Water for One Pound Dry Matter: Transpiration		
	1902	1903	Aver.	1902	1903	Aver.	1902	1903	Aver.
24 hours Weekly	316	801	558	544	379	462	422	270	346
48 hours Weekly	331	730	530	444	389	416	295	236	265
72 hours Weekly	386	688	537	467	441	454	336	270	303
One week, Weekly	335	468	402	545	463	504	398	214	306
48 hours, twice Weekly	369	823	596	553	433	493	423	325	374
None	308	699	504	634	496	565	523	378	451
Average			521			482			341

THE EFFECT OF SHADE.

Results.

The transpiration data reported in this bulletin have, in every case, been obtained by subtracting the amount of water that evaporated from the soil surface of a bare pot, from the amount of water lost by a pot, in every way similarly treated, upon which plants were growing. In general, this method is fairly accurate and perhaps as satisfactory as any of the other ordinary methods for the quantitative determination of transpiration. However, as the plants grew they shaded daily a certain portion of the pot and thereby reduced evaporation. To determine the approximate effect of shade upon evaporation an experiment was conducted in 1902, the results of which are found in Table No. 12. Two series of pots were employed, one wholly shaded and the other fully exposed to the action of the sun's rays. In each set, one-half of the pots were cropped and one-half bare. From the bare pot which was wholly shaded from the direct rays of the sun, over 29 per cent. less water was evaporated than from one standing by its side which was always subjected to the direct action of the sun's rays. On the cropped pot the transpiration formed 48 per cent. of the total loss.

Table No. 12.

THE EFFECT OF SHADE.

(College Loam—Saturated Degree, 20%.)

Pounds of Water Evaporated per Sq. Ft.

Year	1902
Not Shaded	32
Shaded	22
Difference	10
Per Cent Saved	29

THE EFFECT OF THE METHOD OF IRRIGATION.

General.

Water is supplied to plants in irrigated districts by three different methods: 1, by the periodic surface application of water, immediately about the plants; 2, by sub-irrigation, which means that water is applied periodically from below, either by seepage from neighboring sources of water or from perforated pipes specially laid for the purpose; 3, by standing water, which means that the accumulated soil water is within a few feet of the surface and within reach of the plant roots.

Table No. 13.

HISTORY OF POTS.

(Method of Irrigation Experiments.)

	1902	1903	1904
Date of Seeding	June 12	May 28	May 9
Date of Harvesting	Sept. 17	Sept. 18	Aug. 30
First Weighing	July 7	June 13	June 10
Last Weighing	Sept. 17	Sept. 6	Aug. 29
Length of Period	72 days	85 days	80 days
First Irrigation	July 7	June 23	June 24
Last Irrigation	Aug. 23	Aug. 18	Aug. 12
Length of Irrigation Period	47 days	56 days	49 days
Number of Irrigations	3	5	4

The experiments were undertaken in order to secure data on the relative water conserving values of these methods of supplying plants with water. A series of eight pots was arranged for each method of irrigation. Two pots in each series were filled with each of the four soils used in the vegetation house investigations. One-half of the pots were planted to wheat and the corresponding half left bare. The history of the pots in these experiments is shown in Table No. 13. The manner of applying water to the sub-irrigated and standing water pots has already been explained. (page 8.) In every case the standing water was kept within two feet of the surface of the pots.

The Evaporation From Bare Soils.

The results which show the evaporation from the bare soils under the three different methods of irrigation are collected in Table No. 14. The largest loss resulted invariably from surface irrigation. The largest loss in the surface irrigated series occurred from the clay; the sand followed, and the Sanpete clay showed the least. From the sand only about one-

Table No. 14.

THE EVAPORATION FROM BARE SOILS.

(Method of Irrigation Experiments.)

SOIL	Method of Irrigation	Degree of Saturation	Pounds Water Evaporated Per Square Foot 1902	1903	1904	Av.
Sand	Surface	15%	65	121	55	80
	Subirrigation ...	15%	18	23	12	18
	Standing Water.	?	14	29	14	19
College Loam	Surface	20%	51	80	38	56
	Subirrigation ...	20%	23	34	14	24
	Standing Water.	?	17	27	14	20
Sanpete Clay	Surface	25%*	27	71	47	48
	Subirrigation ...	25%	20	22	12	18
	Standing Water	?	4	26	9	13
Clay	Surface	30%†	54	156	116	109
	Subirrigation ...	30%	29			
	Standing Water.	?	16	67	30	38

*Sanpete Clay saturation in 1902 was 20%.

†Clay Saturation in 1902 was 25%.

fifth as much water was lost by sub-irrigation or standing water as by surface irrigation. From the College loam the loss by surface irrigation was about 2½ times larger than by sub-irrigation or standing water. From the Sanpete clay the loss by surface irrigation was about three times as large as by sub-irrigation or standing water. From the clay the loss by surface irrigation was practically three times as great as by standing water. The lesson of the great loss of water under conditions of surface irrigation should be taken to heart by all farmers, whose conditions are such that sub-irrigation is feasible.

The College loam lost more water under conditions of sub-irrigation than either the sand or Sanpete clay. The sub-irrigation experiments on the clay were defective and yielded no results. Under the conditons of standing water, however, the clay lost most water by direct evaporation; followed by College loam, sand and Sanpete clay. It would appear from these findings that the College loam is more permeable to water applied from below than either sand or Sanpete clay.

The total amount of water lost by direct evaporation under conditions of sub-irrigation and standing water was twice as large for the clay as for the sand. The loss from the Sanpete clay was, however, smaller than from any of the other soils. It does not seem probable, therefore, that the loss from surface evaporation, due to the rise of water applied about 2 to 2½ feet below the surface, is wholly due to the fineness of the soil. In fact the clay and College loam which are widely different in their clay content lost water by this method most rapidly.

Yield of Dry Matter.

The yields obtained on the different soils under various systems of irrigation are recorded in Table No. 15. The sand and clay, owing to their infertile nature, gave small and unsatisfactory yields of questionable experimental value. The yields on the College loam and Sanpete clay were very satisfactory.

In the majority of cases, with the exception of the Sanpete clay, the surface irrigation gave the largest yields; though the yields under sub-irrigation were nearly as large. Standing water gave in every case, excepting the Sanpete clay, the smallest yields.

Since water was applied whenever any of the plants on any of the sets showed signs of wilting, it is not easy to understand why the sub-irrigated pots should not give as large yields as the surface irrigated pots. It may be that the larger

Table No. 15.

THE YIELD OF DRY MATTER. (WHEAT.)

(Methods of Irrigation Experiments.)

SOIL	Method of Irrigation	Degree of Saturation	Yields in Grams per Pot 1902	1903	1904	Av.
Sand	Surface	15%	39	147	70	85
	Subirrigation ...	15%	20	87	106	71
	Standing Water.	?	37	9	40	29
College Loam	Surface	20%	237	601	327	388
	Subirrigation .	20%	138	338	328	268
	Standing Water.	?	81		184	132
Sanpete Clay	Surface	25%	109	127	66	101
	Subirrigation ...	25%	107	273	317	232
	Standing Water.	?	44	202	164	137
Clay	Surface	30%	29	190	105	108
	Subirrigation ...	30%	38	124	96	86
	Standing Water.	?	36	65	78	60

development of the roots was near the surface and that surface irrigation gave these roots a better chance to use the water applied. The difference is more probably due, however, to the greater energy expenditure where water must be drawn two feet or more towards the surface. In general, the conclusion may be drawn from these experiments that under equally favorable conditions a somewhat smaller yield is to be expected on soils that are sub-irrigated than on those that are surface irrigated. This does not necessarily mean that more water is required to produce one pound of dry matter.

Water Per Pound of Dry Matter.

The economical use of water is best shown by the number of pounds of water required to produce one pound of dry matter. In Table No. 16 the data covering this point have been

Table No. 16.

EVAPORATION AND TRANSPIRATION. (WHEAT.)

(Method of Irrigation Experiments.)

SOIL	Method of Irrigation	Degree of Saturation	Pounds of Water for One Pound of Dry Matter			
			1902	1903	1904	Av.
Sand	Surface	15%	2899	1638	2823	2453
	Subirrigation ...	15%	5385	1346	1085	2605
	Standing Water.	15%	2028	6590	1100	3239
College Loam	Surface	20%	708	712	828	749
	Subirrigation ...	20%	1052	707	628	796
	Standing Water.	20%	891		593	742
Sanpete Clay	Surface	25%	1469	833	1123	1142
	Subirrigation ...	25%	1040	761	596	799
	Standing Water.	25%	1122	559	684	788
Clay	Surface	30%	4671	1168	1630	2489
	Subirrigation ...	30%	2876	1359	1060	1765
	Standing Water.	30%	2373	1348	1010	1577

assembled. In the case of the sand, the surface irrigation required on the average the least amount of water for the production of dry matter, though it was substantially the same as that required by sub-irrigation. The individual data are, however, so irregular as to make the average of doubtful value. In the case of the College loam the requirements under surface and sub-irrigation and standing soil water were practically the same. In the case of the Sanpete clay, surface irrigation required a larger amount, while the sub-irrigation and the standing soil water were almost identical. In the case of clay, the surface irrigation required the largest amount, while sub-irrigation and standing water were almost alike.

Though these results are quite variable yet it may be inferred from them that practically the same quantities of water are required to produce a pound of dry matter under conditions of sub-irrigation and standing water; and that a somewhat larger quantity is generally required when the water is applied on the surface. Since, however, the direct evaporation of water from the soil is very much larger in surface irrigation than in sub-irrigation or standing water, the actual quantity of water passing through the plant for one pound of dry matter is probably no larger when the water is applied from the surface. Moreover, it is clear that while a smaller yield is usually produced on soils that are supplied with water from below, yet the cost of water for each pound of plant substance so produced is less than for crops grown on surface irrigated soils. This is distinctly in favor of sub-irrigation whenever it is practicable.

The Transpiration Factor.

Table No. 17 gives the averages of a number of somewhat scattered results dealing with transpiration under various

Table No. 17.

TRANSPIRATION. (WHEAT.)

(Method of Irrigation Experiments.)

SOIL	Pounds of Water for One Pound of Dry Matter		
	Surface	Sub-Irrigation	Standing Water
Sand		2017	1169
College Loam.....	490	649	542
Sanpete Clay......		658	657
Clay		1785	996

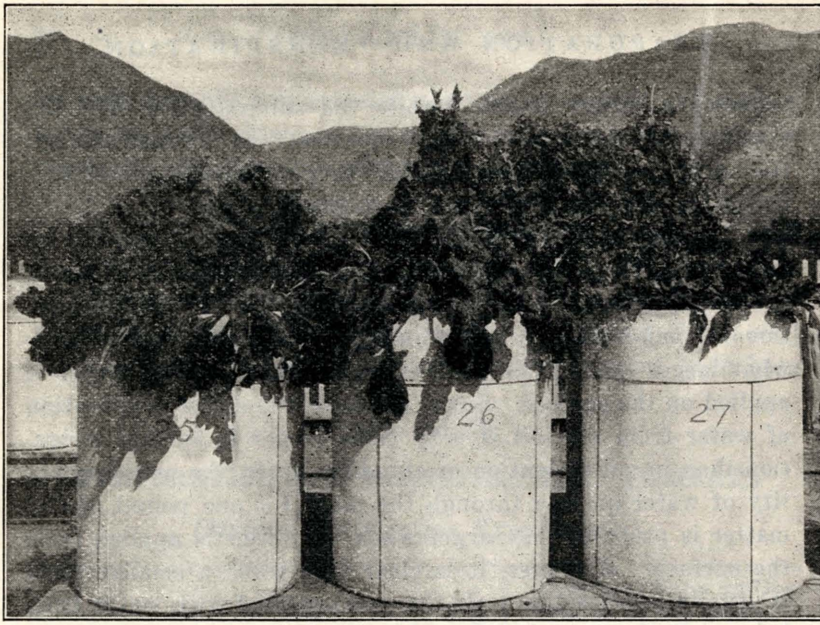

Fig. 6.—Sugar Beets in Experiments on Varying Amounts of Water.

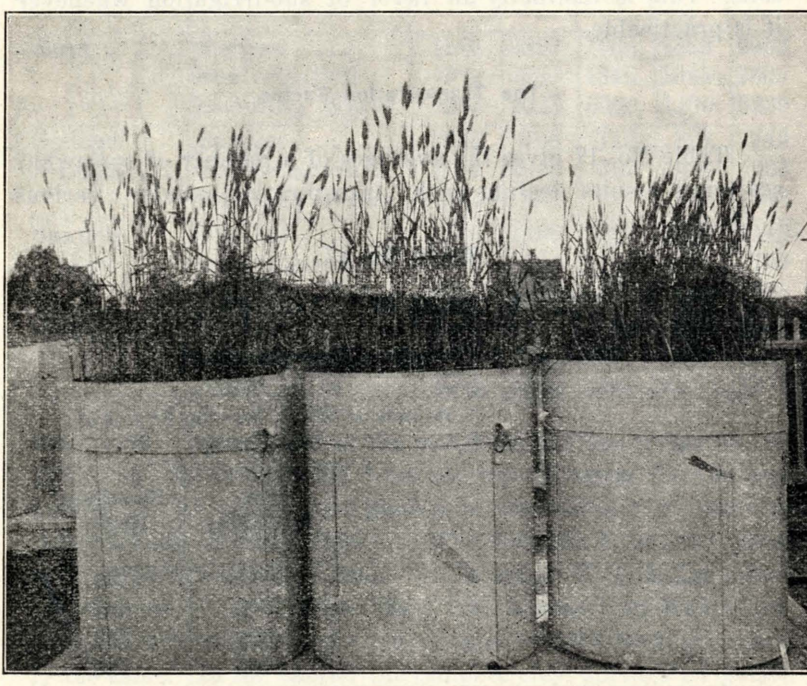

Fig. 7.—Wheat in Saturation Experiments.

methods of irrigation. Less water appears to be required to pass through plants for the production of one pound of dry matter under conditions of standing water than under sub-irrigated conditions. Whether or not a larger amount would be required on surface irrigated soils can not be determined from this table, though the results of Table No. 16 indicate that this would not be the case. It is clear enough, however, that the method of applying water really affects the transpiration of water as related to the production of dry substance. It is often taught that under any and all conditions the production of a certain amount of dry substance requires the use of a definite amount of water. In the light of the investigations already recorded in this bulletin and those that will be recorded later on, this notion can not longer be held.

Inches of Water Used.

Table No. 18 shows, simply as a matter of record, the inch equivalent of the amounts of water applied to the pots in the

Table No. 18.

INCHES OF WATER USED. (WHEAT.)

(Method of Irrigation Experiments.)

(Average of 1902-1904.)

SOIL		Method of Irrigation		
		Surface	Sub-Irrigat'n	Standing Water
Sand	Bare	15	3	4
	Cropped	25	15	8
College Loam	Bare	11	5	4
	Cropped	40	27	14
Sanpete Clay	Bare	9	4	3
	Cropped	15	23	12
Clay	Bare	21	17	7
	Cropped	24	20	11

tests dealing with the method of irrigation. With the exception of the cropped pots containing loam soil, which were surface irrigated, the amounts of water used were well within the limits of the amounts of water ordinarily used in actual farm practice.

THE EFFECT OF SOIL SATURATION ON CROPS.

General.

The investigations planned for the vegetation house included the collection of information concerning the loss of water under different conditions of saturation of the soil. A series of fifteen pots, filled with College loam, were employed in the experiment. Three pots were left bare; three were

Table No. 19.

HISTORY OF POTS.

(Effect of Saturation Experiments.)

	1902	1903	1904	1905
Date of Seeding	June 12	May 28	May 9	May 7
*Date of Harvesting	Sept. 17	Sept. 5	Sept. 10	Sept. 20
First Weighing	July 5	June 15	June 10	May 12
Last Weighing	Sept. 17	Sept. 5	Aug. 29	Sept. 19
Length of Period	74 days	83 days	80 days	130 days
First Irrigation	July 5	June 23	June 21	May 27
Last Irrigation	Sept. 5	Aug. 28	Aug. 25	Sept. 27
Length of Irrigation Period	62 days	66 days	65 days	123 days
Number of Irrigations	4	14	9	10

*Sugar Beets in all cases were harvested later—about five weeks after grain harvest.

planted to wheat; three to sugar beets; three to corn, and three to peas. One pot in each set received at each irrigation enough water to make 10 per cent. of the dry weight of the soil; the second received 15 per cent., and the third, 20 per cent.

Evaporation From Bare Soils.

Table No. 20 shows the evaporation of water during the four seasons, 1902 to 1905, from the pots on which no plants were grown. In every case the total evaporation increased with the increase in the saturation per cents. In fact, the in-

Table No. 20.

TOTAL EVAPORATION OF WATER FROM BARE SOILS.

(Saturation Experiments; College Loam.)

Saturation Degree	Loss in Pounds per Square Foot				
	1902	1903	1904	1905	Average
10%	9	32	9	16	16
15%	23	......	10	30	21
20%	51	80	38	69	60

Table No. 21.

THE RATIO OF LOSSES FROM EVAPORATION FROM BARE SOILS.

(Saturation Experiments; College Loam.)

Saturation Degree	1902	1903	1904	1905	Average
10%	1.00	1.00	1.00	1.00	1.00
15%	2.46	......	1.11	1.91	1.83
20%	5.50	2.52	4.43	4.45	4.23

creased loss was usually much larger than the increased degree of saturation. This is shown more clearly in Table No. 21 which exhibits the ratio of the losses of water from bare soils under varying degrees of saturation. In 1902 the pots that received 20 per cent. of water at each irrigation lost 5½ times more water than did those which received only 10 per cent. In 1903 the ratio was over 2½; and in 1904 and 1905 nearly 4½. In general, then, under the somewhat unnatural conditions that prevailed at the vegetation house, doubling the saturation percentage more than quadrupled the loss of water for the season. This tendency has been verified in field experiments to be published later. However, under normal field conditions the increase of loss is not nearly so great as in the pot experiments. Certainly, these results teach that heavy irrigations must be followed by careful and thorough cultivation, else great losses of water will occur.

The Yields of Dry Matter.

Table No. 22 shows the yields of dry matter obtained from the pots on which different crops were grown under varying degrees of saturation. In studying this table it must be remembered that the whole set was governed by the plant which

Table No. 22.

EFFECT OF SATURATION ON YIELD.

(College Loam.)

CROP	Saturation	Yield of Dry Matter in Grams per Pot 1902	1903	1904	1905	Av.	Ratio
Wheat.......	10% ...	181	137	65	93	119	1.00
	15% ...	82	349	172	131	184	1.54
	20% ...	237	601	326	93	314	2.65
Sugar Beets.......	10% ...	93	300	160	88	160	1.00
	15% ...	320	760	292	192	391	2.44
	20% ...	320	600	699	476	524	3.28
Corn.........	10% ...	154	297	223	79	189	1.00
	15% ...	412	654	396	93	389	2.05
	20% ...	427	567	411	354	439	2.32
Peas.........	10% ...	32	160	75	41	79	1.00
	15% ...	107	229	89	66	123	1.60
	20% ...	140	451	74	74	185	2.40

first showed signs of wilting, that is, when a plant on any one of the pots showed need of water the whole set was irrigated. Naturally, the plants growing on the pots of the lowest saturation degree first showed the need of water. No plant, however, was made to suffer; the plants were given all the water that they could use; the difference was wholly in the ease of availability of water.

Doubling the saturation degree increased the yields of wheat, corn and peas about 2¼ times and the yield of sugar beets over three times. In the case of corn there was only a slight increase by raising the saturation degree from 15 to 20 per cent. In fact, for the growing of corn the 15 per cent saturation appears to be the most profitable. Raising the saturation degree from 10 to 15 per cent caused an almost proportional increase in the dry matter. In general, it is remarkable to note the manner in which the available moisture and the yield of dry matter kept pace with each other. Since, in this experiment, an abundance of water was at hand, but not equally easily available, these findings suggest that the yield of dry matter is proportional to the ease with which water may be obtained by the plant roots. Under field conditions, where the total quantity of water is frequently limited and the distribution is variable, different results would naturally be obtained. Moreover, in these pots there was no equivalent of the large amount of water stored in the soil in the spring from the natural precipitation. The same uniformity of variation must not, therefore, be expected on fields cultivated in the ordinary manner. This will be discussed more fully in succeeding reports.

Water Per Pound of Dry Matter.

Perhaps the most interesting question to be asked in connection with the degree of saturation experiments is: Does the saturation per cent have any effect upon the number of pounds of water required to produce one pound of dry matter? Table No. 23 throws some light on this question. The column headed "Average" exhibits a most surprising uniformity of results, under varying degrees of saturation, for each of the crops. The total amounts of water used to produce a pound of dry matter under the 10 and 20 per cent saturations are almost identical for wheat and sugar beets, and nearly so for corn and peas. It is also noteworthy that corn and sugar beets require just a little more than one-half as much water to produce a pound of dry matter as do wheat and peas. It must be noted, however, that the dry matter of the sugar beets refers to both tops and roots. These results teach that on the college loam used in these pot experiments the saturation degree had very little, if any, effect upon the number of pounds of water necessary to produce one pound of dry matter.

Table No. 23.

EFFECT OF SATURATION ON EVAPORATION AND TRANSPIRATION.

(College Loam.)

CROP	Saturation	Pounds of Water for One Pound of Dry Matter				
		1902	1903	1904	1905	Av.
Wheat........	10%	324	661	943	2150	1019
	15%	1232	719	809	1321	1020
	20%	708	712	828	1811	1015
Sugar Beets........	10%	780	371	722	821	674
	15%	512	474	766	414	542
	20%	656	886	480	676	675
Corn..........	10%	575	432	479	977	616
	15%	434	480	445	1030	597
	20%	575	457	436	585	513
Peas..........	10%	2069	621	672	1065	1107
	15%	929	805	1337	998	1017
	20%	1342	1040	2434	1110	1232

The Tran-piration Factor.

It is unfortunate that the available data are not sufficient to complete Table No. 24, for, in view of the conclusion of the preceding section, it becomes of great importance to learn to what extent, if any, the saturation degree affects the transpiration; that is, the amount of water that actually passes through the plant. From Table No. 24 it would appear that sugar beets and corn require a little less water for the production of one pound of dry matter with a 20 per cent saturation

Table No. 24.

EFFECT OF SATURATION ON TRANSPIRATION.

(College Loam.)

CROP	Saturation	Pounds of Water for One Pound of Dry Matter				
		1902	1903	1904	1905	Av.
Wheat........	10%	258	340	755	356	427
	15%	839	....	730	998	....
	20%	511	523	664	261	489
Sugar Beets........	10%	639	227	645	570	520
	15%	411	....	790	197	....
	20%	420	696	403	469	499
Corn..........	10%	490	280	424	697	473
	15%	356	....	411	574	....
	20%	406	256	276	306	311
Peas..........	10%	1658	269	510	525	740
	15%	628	....	1186	353	....
	20%	808	789	1704	....	....

degree than with a lower saturation degree. When the soil is saturated to a 20 per cent degree the plants have less labor to perform in obtaining water than when the saturation is lower; this probably makes possible a more economical production of dry matter. With wheat and peas, however, this conclusion can not be drawn with the same safety, for the evidence of the data at hand is that these two crops require a larger number of pounds of water to produce one pound of dry matter when the saturation degree is high than when it is low. The figures of Table No. 24 are subject to considerable experimental correction and should not be considered final. The total amounts of water required by various plants vary considerably, and we shall probably find also that the water equivalents of the dry matter produced vary under the influence of varying saturation degrees.

Inches of Water Used.

Table No. 25 shows the average number of inches of water used on the various pots during the experimental seasons. In

Table No. 25.

INCHES OF WATER USED.

(Saturation Experiments, College Loam.)

CROP	Saturation	Average (1902-1905)	Ratio
Bare	10%	3	1.00
Bare	15%	4	1.29
Bare	20%	11	3.68
Wheat	10%	9	1.00
Wheat	15%	22	2.52
Wheat	20%	36	4.01
Sugar Beets	10%	12	1.00
Sugar Beets	15%	28	2.31
Sugar Beets	20%	47	3.89
Corn	10%	10	1.00
Corn	15%	17	1.71
Corn	20%	35	3.58
Peas	10%	12	1.00
Peas	15%	19	1.57
Peas	20%	26	2.13

every case but one the ratios of smallest and largest amounts used is several times larger than the ratio between the corresponding saturation degrees. This only emphasizes the law already stated, that the loss of water from college loam, whether cropped or uncropped, usually increases much more rapidly than the increase in the degree of saturation. It may be noted that the total amounts of water used by peas were in almost exact proportion to the increase in saturation degree. With the exception of the maximum degrees of saturation, the quantities of water lost were well within the limits of actual practice.

THE EFFECT OF SATURATION ON DIFFERENT SOILS.

General.

The saturation experiments just described were duplicated on sand, Sanpete clay and clay soils. Only one crop, wheat,

Table No. 26.

HISTORY OF POTS IN SATURATION VS. SOIL EXPERIMENTS.

	1902	1903	1904	1905
Date of Seeding..........	June 12	May 28	May 9	May 7
Date of Harvesting........	Sept. 17	Sept. 5	Sept. 10	Sept. 19
First Weighing...........	July 7	June 13	June 10	May 13
Last Weighing...........	Sept. 17	Sept. 5	Aug. 29	Sept. 11
Length of Period..........	72 days	84 days	80 days	121 days
First Irrigation...........	July 7	June 23	June 24	May 31
Last Irrigation...........	Aug. 23	Aug. 18	Aug. 12	Sept. 11
Length of Irrigation Period	47 days	56 days	49 days	103 days
Number of Irrigations.....	3	5	4	6

was grown. The degrees of saturation for the sand were 7.5 per cent, 10 per cent and 15 per cent; for the Sanpete clay, 15 per cent, 20 per cent and 25 per cent; for the clay, 20 per cent, 25 per cent and 30 per cent.

The Yields of Dry Matter.

Table No. 27 shows the yields of dry matter produced under varying saturation degrees upon the soils used in these experiments. Though the number of failures upon the sand and Sanpete clay makes many comparisons impossible, yet those

Table No. 27.

EFFECT OF SATURATION ON YIELDS ON VARIOUS SOILS.

SOIL	CROP	Saturation	Grams of Dry Matter per Pot					Ratio
			1902	1903	1904	1905	Av.	
Sand.....	Wheat	8%	39	....	73	....	56	1.00
	Wheat	10%	(42)	(162)	....	....	....	....
	Wheat	15%	39	(147)	70	....	55	0.98
Sanpete	Wheat	15%	60	118	106	....	95	1.00
Clay....	Wheat	20%	(105)	(97)	....	(52)	....	....
	Wheat	25%	109	127	66	(181)	101	1.06
Clay.....	Wheat	20%	40	151	68	20	69	1.00
	Wheat	25%	44	146	102	36	82	1.18
	Wheat	30%	29	190	105	34	89	1.29

that may be made safely, found in the "Average" column, no doubt indicate the general law lying behind the relations that were under investigation. In no case did the 15 per cent, or maximum degree of saturation of the sand, produce the largest yield of dry matter. On the contrary, the 10 per cent saturation produced the best results. The average yield under 15 per cent saturation is practically identical with that under 7.5 per cent. In the case of Sanpete clay the evidence is somewhat contradictory and favors slightly the view that the highest degree of saturation produces the largest amount of dry matter. The increase, however, is very small, and far from proportional to the increase in the degree of saturation. The series of experiments dealing with clay is complete and shows that on the average the largest yield of dry matter was obtained under the highest saturation degree. The difference in yield, however, is not proportional to the increase in saturation degree. The results from these three soils are contrary to those obtained from the College loam. This is probably due to fundamental differences in the soils.

Pounds of Water Per Pound of Dry Matter.

The number of pounds of water required to produce one pound of dry matter under various degrees of saturation upon different soils is shown in Table No. 28. The general tendency of the three soils is, clearly, that under the highest saturation degree more water is required for the production of one

Table No. 28.

EFFECT OF SATURATION ON EVAPORATION AND TRANSPIRATION.

SOIL	CROP	Saturation	Pounds of Water for One Pound of [Dry Matter]				
			1902	1903	1904	1905	Av.
Sand....	Wheat	8%	2182	....	1283	....	1733
		10%	(2246)	(1155)	....	....	....
		15%	2899	(1638)	2823	....	2861
Sanpete Clay...	Wheat	15%	1403	1067	912	...	1127
		20%	(1142)	(995)	....	(2280)	....
		25%	1469	833	1123	(1289)	1142
Clay....	Wheat	20%	1733	990	1598	5887	2552
		25%	2525	1035	1155	5056	2443
		30%	4671	1168	1630	6468	3484

pound of dry matter than under lower saturation degrees. This is especially well marked with the sand and the clay, the two infertile soils, and only slightly in evidence with the Sanpete clay, the fertile soil. The net results of these tests indicate that the higher saturation degrees, considered with reference to the quantity of water for each pound of dry matter produced are essentially wasteful. However, in view of the fact that on the college loam, a very fertile soil, the variation of the saturation degree did not affect the water cost of dry matter, and that on the Sanpete clay, another very fertile soil, the effect was not strong, it may be suggested that on fertile soils it is not so wasteful to apply water heavily, as it is on infertile soils. These observations connect themselves with the question of soil fertility which runs through all of the investigations reported in this bulletin.

Inches of Water Used.

Table No. 29 shows the number of inches of water used in these experiments. In only two cases, out of the nine observations, does the ratio of the total loss of water exceed the ratio of the increase of saturation degree. In these cases the increase is very small. In all the other cases the loss of water

Table No. 29.

INCHES OF WATER USED.

(Saturation Experiments.)

SOIL	CROP	Saturation	Average (1902-1905)	Ratio
Sand.....	Wheat	7.5%	12	1.00
	Wheat	10%	17	1.38
	Wheat	15%	22	1.85
Sanpete	Wheat	15%	14	1.00
Clay....	Wheat	20%	15	1.07
	Wheat	25%	19	1.41
Clay.....	Wheat	20%	15	1.00
	Wheat	25%	19	1.26
	Wheat	30%	25	1.64

does not keep pace with the increased saturation degree. This emphasizes the vital difference between these soils and the College loam. The total quantities of water used are well within the limits of ordinary farm practice.

THE EFFECT OF PREVIOUS SOIL TREATMENT.

Experiments of 1905.

These investigations have indicated repeatedly that the mechanical and chemical and perhaps biological condition of the soil has a definitely marked effect upon the use of water by plants. The persistent evidence of this led to a series of tests to determine whether the previous treatment of the soil would have any effect upon the quantity of water required for plant production. In 1905, a series of pots, on half of which crops had been grown the preceding three years, and the other half of which had been bare, were planted to corn. Half of the pots were cultivated and the other half were left uncultivated.

The Yield of Dry Matter.

The results of the experiment will be found exhibited in Table No. 30. From the three soils under examination the yield of dry matter was larger in every case on the pots which had remained bare during the preceding three years; the increase was remarkably high, varying from 34 to 328 per cent. The sand pots were also cropped, but the yields were obtained only from those pots that had been cropped before. The pots that had remained bare during the preceding three years failed to bring their plants to maturity. This fact is not easy of explanation, though it must be remembered that the sand was an extremely infertile soil, almost wholly devoid of organic matter and that the cropped pots were in a better condition of tilth than those which had remained bare throughout the three year period.

Pounds of Water Per Pound of Dry Matter.

The second part of Table No. 30 shows the effect on the bare versus cropped treatment upon the number of pounds of water for the production of one pound of dry matter. In every case, the soils that had been cropped during the preceding three years required more water for the production of one pound of dry matter than those which had remained bare during that period. In the case of the College loam the saving was about 13 per cent; of the Sanpete clay about 38 per cent, and of clay about 770 per cent.

Table No. 30.

EFFECT OF PREVIOUS SOIL TREATMENT.

(Pots Grown to Corn in 1905.)

SOIL	Crops During the Preceding Three Years	Yields of Dry Matter per Pot		Average (Grams)
		Cultivated	Not Cultivated	
College	Bare	327	287	307
Loam...	Cropped	207	252	229
Sanpete	Bare	385	343	364
Clay....	Cropped	128	41	85
Clay......	Bare	47	....	47
	Cropped	33	....	33
Pounds of Water for One Pound of Dry Matter.				
College	Bare	512	634	573
Loam..	Cropped	593	725	659
Sanpete	Bare	567	534	550
Clay...	Cropped	774	1003	889
Clay.....	Bare	1739	....	1739
	Cropped	7466	....	7466

(Saturation of College Loam, 20%; Sanpete Clay, 25%; Clay, 30%.)

These results teach clearly and emphatically that the fertile condition of the soil, induced by fallowing and cultivation, makes it possible to produce dry matter with a less amount of water, than can be done on soils that are cropped continuously. The lesson is one that should be heeded wherever water is the limiting factor in crop production. Especially does this throw light upon the great beneficial effect of summer fallowing in dry farming.

Experiments of 1908.

The investigations in the vegetation house were suspended for two years and all the pots during this period were left exposed to the rains, snows, wind and sunshine. The tendency of this period would naturally be to bring all the soils to approximately the same condition. In the spring of 1908 the experiments were resumed. The attempt was then made to determine to what extent the treatment given the soils previously to these two years of rest would affect the water requirements of crops to be grown on the soils. Fourteen pots of College loam were selected for the experiments. During the four years preceding the two years of rest, four had been cropped every year; five had been cropped three years and five had been cropped one year.

The Results.

In Table No. 31 the average results of the trials are shown. The yields of dry matter were practically the same for the three sets. The small differences are within easy reach

Table No. 31.

EFFECT OF PREVIOUS TREATMENT.

(Corn Crop Grown in 1908, College Loam, 20% Saturation.)

Previous Treatment (1902-1905)	Number of Trials	Yield of Dry Matter Grams per Pot	Pounds of Water for One Pound of Dry Matter
Cropped Four Years	4	393	453
Cropped Three out of Four Years	5	370	463
Cropped One out of Four Years..	5	395	425

of experimental error. Likewise the number of pounds of water required for the production of one pound of dry matter does not differ greatly for the three sets, though the smallest number coincides with the soil that had received the longest resting period. The truth developed in Table No. 30 holds, therefore, in these tests also, though the differences are small as would be expected from the fact that the two years of rest had permitted all the soils to approach a state of equality. The value of fallowing or its equivalent is again demonstrated.

THE EFFECT OF FERTILIZERS.

Experiments of 1904, 1905.

So strong did the conviction become early in these investigations that the available plant food of the soil had a direct effect not only upon the yield, but upon the transpiration, that a series of tests were undertaken to determine directly the effect that the addition of artificial fertilizers would have upon the water requirements of the various soils and the crops growing upon them. In 1904 a series of pots, filled with college loam, which had been treated alike, were set aside for this work. They were divided into five sets, which, in 1904, received fertilizers as follows: The first received no fertilizer; the second, 4 pounds of ordinary stable manure, which was carefully incorporated with the upper 6 inches of the soil; the third, 0.1 per cent of sodium nitrate, on the basis of dry soil in the upper six inches; the fourth, 0.01 per cent of sodium nitrate and the fifth, 0.1 per cent of potassium chloride. The chemical fertilizers in like amounts were also added to the same pots in 1905.

The Evaporation From Bare Soils.

Table No. 32 shows the results obtained.

In 1904 the addition of fertilizers increased in every instance the total evaporation from the bare soils, but the effect was least marked from the addition of potassium chloride and greatest from the addition of 0.01 per cent of sodium nitrate. In 1905 the effect likewise, was marked, but in that year the largest increase was from the addition of 0.10 per cent of sodium nitrate. The next largest increase was from the addition of 0.01 per cent of sodium nitrate. The pot which had received manure evaporated the least amount of water.

The Yield of Dry Matter.

The addition of fertilizers also affected the production of dry matter. In 1904, only, the addition of 0.01 per cent of sodium nitrate failed to produce an increase of dry matter, above the yield on the unmanured pot. In 1905, all the fertilized pots produced more dry matter than the one unfertilized pot, though the addition of the 0.01 per cent of sodium nitrate produced only a trifle more dry matter than the pot which received no fertilizer. The pot that received the potas-

Table No. 32.

EFFECT OF FERTILIZERS. 1904-1905.

(College Loam, 20% Saturation; Corn Grown Both Seasons.)

YEAR	Nothing Added	FERTILIZERS ADDED Evaporation from Bare Soils. (Pounds per Sq. Ft.) 4 lbs. Manure	1-10 per cent. Sodium Nitrate	1-100 per cent. Sodium Nitrate	1-10 per ct. Potassium Chloride
Evaporation from Bare Soils. (Pounds per Sq. Foot.)					
1904	25	39	39	62	37
1905	......	39	73	62	49
Average ...	......	39	56	62	43
Yield of Dry Matter. (Grams per Pot.)					
1904	156	163	202	131	181
1905	251	401	394	263	439
Average ...	204	281	298	202	310
Pounds of Water for One Pound of Dry Matter. (Total.)					
1904	1133	949	857	933	1137
1905	725	456	413	467	591
Average ...	929	703	635	700	864
Pounds of Water Transpired for One Pound of Dry Matter.					
1904	908	613	585	257	848
1905	......	315	151	237	431
Average ...	......	464	368	247	639

sïum chloride led in the yield, followed by the pot which received 0.01 per cent of sodium nitrate.

Pounds of Water Per Pound of Dry Matter.

The effect of the fertilizer was felt strongly in the amount of water required for the production of one pound of dry matter. In 1904 all the pots, with the exception of the one receiving potassium chloride, produced dry matter at a less water cost than the pot which was not fertilized. In 1905 all the fertilized pots produced dry matter at a less water cost than the unfertilized pot. The average of the two years shows a decïded reduction of the quantity of water required per pound of dry matter as a result of adding fertilizers to these soils.

The Transpiration Factor.

The number of pounds of water actually transpired for each pound of dry matter was likewise reduced by the addition of fertilizers. In 1904 the plants on all fertilïzed pots transpired less water than did the plants on the unfertilized pot. Unfortunately, the necessary data for 1905 for the unfertilized pot were lost so that no comparison can be made, but there can be no good reason for believing that the same law would not hold durïng that year, especially in view of the fact that the transpiration constants during that year for the other pots in the experiments were very low.

It should be observed that the College loam on which these tests were made is a very fertile soil which at the time of the experiments was in a most excellent condition. Therefore, the effects of the fertilizers could not be expected to be so marked as on an infertile soil. In fact, it was an error of judgment to undertake these experiments on so fertile a soil if the largest effects were to be observed. However, these tests bear out the previous observations noted throughout this bulletin that the available plant food in soils exerts a direct effect upon the water requirements of soils and crops.

Previous Soil Treatment.

Most of the pots which were included in the experiments recorded in Table No. 30, after havïng been exposed to the weather for two years were planted to corn in 1908. Table No.

33 gives the yields of dry matter and the pounds of water for each pound of dry matter produced. The results, as was to be expected, are irregular. Any beneficial effect of previous resting is not clearly evident. This may in part be due to a puddling effect of the fertilizers on bare soils. The table is inserted merely as a matter of record.

Table No. 33.

EFFECT OF PREVIOUS SOIL TREATMENT AND FERTILIZERS.

(Crop of Corn Grown in 1908; College Loam, 20% Saturation.)

	Crop Condition 1902-1905	Fertilizers in 1904 and 1905		
		1-10 per cent. Sodium Nitrate	1-100 per cent. Sodium Nitrate	1-10 per ct. Potassium Chloride
Yield of Dry Matter in Grams, per Pot.	Cropped ...	182	230	374
	None	267	393	284
Pounds of Water for One Pound of Dry Matter (Total) ..	Cropped ...	673	450	483
	None	653	536	535

Experiments in 1908.

In the spring of 1908, a lot of miscellaneous pots containing the soils used in these experiments were collected and grouped into sets for the purpose of further testing the effect of fertilizers upon the water requirements of soils and crops. These various pots had been treated very differently during the four years of experimental work, in the matter of soil treatment, crops grown, method of irrigation and the quantity of water applied. All of the pots, however, had been exposed to the atmospheric agencies during the years, 1905-1908. Each soil class was grouped into 8 sub-classes, each of which received a different fertilizer treatment as indicated in Table No. 34. The amounts of fertilizer applied in each case was nearly five times larger than in 1904 and 1905. As a result the depressing effect of the fertilizers is observed in a number of cases.

Table No. 34.

EFFECT OF FERTILIZERS (1908).

(Corn.)

		None	Potash	Phosphate	Nitrate	Potash Nitrate	Potash Phosphate	Nitrate Phosphate	Potash Phosphate Nitrate
Sand...	Yield of Dry Matter (Grams per Pot)...............	78	33	125	49	....	65	137	52
	Pounds Water for one pound Dry Matter (Total)....	1591	2093	1100	1540	....	1375	507	1355
	Pounds Water Transpired for one pound Dry Matter..	1012	686	735	555	....	671	178	459
College Loam	Yield of Dry Matter (Grams per Pot)...............	315	381	288	257	249	288	411	165
	Pounds Water for one pound Dry Matter (Total)....	503	429	552	652	637	493	452	583
	Pounds Water Transpired for one pound Dry Matter..	357	308	391	471	450	333	339	303
Sanpete Clay.	Yield of Dry Matter (Grams per Pot)...............	321	415	242	382	314	266	....	....
	Pounds Water for one pound Dry Matter (Total)....	437	393	549	494	474	541	....	....
	Pounds Water Transpired for one pound Dry Matter..	306	292	375	385	280	383	....	....
Clay...	Yield of Dry Matter (Grams per Pot)...............	76	152	209	395	179	102	340	521
	Pounds Water for one pound Dry Matter (Total)....	1331	705	757	484	633	....	476	445
	Pounds Water Transpired for one pound Dry Matter..								

(Saturation of Sand, 15%; College Loam, 20%; Sanpete Clay, 25%; Clay, 30%.)

Sand.

The sand, as usual, behaved irregularly. The yield of dry matter on the sand was increased only by the phosphates and phosphates plus nitrates. The addition of nitrates and potash alone or in combination, had a depressing effect upon the process of assimilation. The total number of pounds of water required for the production of one pound of dry matter was increased by the addition of potash alone and decreased in every other case. The amount of water transpired for a pound of dry matter on the pots that had received artificial fertilizers was in every case very much smaller than that required on the pot that had received no artificial fertilizers. The experiments on the sand confirm the law that available plant food affects the water requirements of soils and plants.

College Loam.

The production of dry matter on the College loam was increased only by the application of nitrates and phosphates plus nitrates; in all the other cases there was a distinct falling off in yield. The total number of pounds of water required to produce a pound of dry matter on the College loam was quite variable. In three cases it was lower than the amount required on the pot which received no fertilizer and in four cases it was higher. The actual amount of water transpired for a pound of dry matter, likewise, showed variability, being smaller in four cases than the amount for the unfertilized pot and larger in three cases.

Sanpete Clay.

The Sanpete clay, like the College loam, was favorably affected only in part by the addition of fertilizers. The addition of potash and potash plus nitrate increased the yield of dry matter, while the other fertilizers decreased the yield. The total amount of water required to produce one pound of dry matter was in all but one case larger on the fertilized pots than on the unfertilized one. The amount of water transpired to produce a pound of dry matter was larger in all but two cases than on the unfertilized pot.

Clay.

The addition of fertilizers to the clay increased the yield in every case. With the complete fertilizer the increase was over six times the yield on the unfertilized pot. The total number of pounds of water required to produce one pound of dry matter was likewise in every case very much smaller on the fertilized than on the unfertilized pots. Owing to an accident some vital data were lost and it was therefore impossible to determine the pounds of water transpired to produce one pound of dry matter on the clay soils, but in all probability the differences there would even be greater than recorded for the total amount.

Discussion.

Since this bulletin does not pretend to deal with questions of soil fertility except as they connect themselves with the evaporation and transpiration of water, it will not be necessary to attempt an explanation of the effects of the various fertilizers upon the yields of dry matter from the experimental soils. It may be suggested, however, that the College loam and Sanpete clay, which are both very fertile soils, had been able, under the atmospheric influences of the two preceding years, to liberate considerable plant food. They could not therefore be expected to give as definite results as would poorer soils. The sand, in the matter of transpiration, reacted distinctly to fertilizers, and the clay reacted to an even greater degree. As before stated, the pots in this experiment were not of uniform condition; and probably the effects of the previous treatment overshadowed in some cases the effect of the fertilizers. Finally, it must be kept in mind that *excessive* quantities of fertilizers were used, which naturally produced abnormal results.

As the net results of the experiments dealing with the effect of fertilizers upon the transpiration and evaporation it may safely be concluded that the application of artificial fertilizers to a soil which requires them will not only increase the yield of dry matter, but will make it possible for plants to produce dry matter at a lower water cost than on similar soils which have not received such artificial stimulus. This is a vital matter in the agriculture of a region where water is an essential consideration.

TH EFFECT OF SEASONS.

It is not at all a new thought that the seasons affect crop growth, even when the conditions at the time of seeding and the supply of water throughout the season are unchanged, but in an irrigated country, where the farmer makes crops grow though it does not rain, the effect of the seasons is often underestimated.

In Table No. 35 will be found a few results showing the effect of the seasons upon the yield of dry matter, total evaporation and transpiration. The soil was College loam, and the pots were those used in the experiment on the effect of cultivation. It will be noticed that with the same cultural care and with an equal abundance of water, the yield of dry matter in grams per pot varied from 211 in 1904 to 689 in 1903. The years 1902, 1905 and 1908 were almost identical, averaging between 320 and 346 grams. The difference is even more pronounced in the total number of pounds of water required to produce one pound of dry matter. In 1903 when the yield was highest, the water equivalent of the dry matter was the lowest. In 1904 when the yield was the lowest, the water equivalent was the highest. With the exception of the year 1904, however, there is no very great difference in the number of pounds required for a pound of dry matter, though the variation is sufficient to indicate clearly that the seasons have a direct effect also upon the total amount of water required to produce one pound of dry matter.

The transpiration factor was similarly influenced. In the years 1903 and 1905, though the yield of dry matter was more than twice as large in the former as in the latter year, yet the number of pounds of water transpired for a pound of dry matter was almost the same. In 1904, when the yield was smallest, the transpiration factor was the highest. The effect of the seasons is clearly shown also in the variation of this factor.

Even on the bare soils the effect of the seasons is very clearly shown, as may be found in Table No. 36. On the sand, College loam, Sanpete clay and the clay, the variations were marked. In every case the largest evaporation occurred in

Table No. 35.

THE EFFECT OF THE SEASONS.

	1902	1903	1904	1905	1908
Yield of Dry Matter (Grams per Pot)	346	689	211	320	341
Total Loss of Water (lbs. Water for one lb. D. M.)	538	449	878	589	484
Transpiration (lbs. Water for each lb. D. M.)	402	284	577	288	357
Yield of Dry Matter (Number of Trials)	9	9	8	8	25
Total Loss of Water (Number of Trials)	9	9	8	8	25
Transpiration (No. of Trials).....	9	9	8	5	8

Table No. 36.

THE EFFECT OF THE SEASONS.

Loss of Water from Bare Soils. (Pounds per Square Foot.)

	1902	1903	1904	1905
Sand	50	115	54	...
College Loam	33	72	41	58
Sanpete Clay	56	85	50	60
Clay	48	129	81	11
Number of Trials.				
Sand	3	3	3	...
College Loam	9	9	7	5
Sanpete Clay	3	3	3	1
Clay	3	3	3	1

1903. While not the lowest in every case, the season of 1902 seemed to cause least evaporation. Since the intrinsic effect of the seasons can not be controlled, such results can not be of great practical importance, yet the table is inserted as a matter of record as it may explain variations otherwise difficult to understand.

THE EFFECT OF CROP AND SOIL.

The crop and the soil are both powerful in their relation to soil moisture. This fact is brought out well in Table No. 37. A study of Table No. 37 shows first that the amount of water actually used by a crop during any one season varies greatly with the soil. For example, to produce one pound of dry matter of corn required, on sand and clay, between 1600 and 1700 pounds of water, while on the College loam and Sanpete clay between 552 and 626 pounds were required. In other words, it required nearly three times as much water to produce a pound of dry corn on sand and clay as on College loam and Sanpete clay. When the pounds of water actually transpired

Table No. 37.

WATER EQUIVALENTS OF DRY MATTER.

	Sand	College Loam	Sanpete Clay	Clay	Sand	College Loam	Sanpete Clay	Clay
	Number of Trials				Total Pounds Water Lost for 1 Pound of Dry Matter			
Corn	13	67	16	14	1616	552	626	1682
Wheat	16	16	18	21	2445	1017	1078	2445
Sugar Beets	....	12	....	....	....	630	....	....
Peas	....	12	....	....	....	1118	....	....
	Number of Trials				Pounds Water Transpired for One Pound Dry Matter			
Corn	11	46	12	3	561	386	408	601
Wheat	2	15	2	5	2017	546	658	917
Sugar Beets	....	11	....	....	....	497	....	....
Peas	....	10	....	....	....	843	....	....

for each pound of dry matter are considered, the differences are not nearly so large, though there is a difference of 25 per cent. in favor of the College loam and Sanpete clay.

When, on the other hand, different crops growing on the soil are compared, differences almost as large are observed. For instance, to produce one pound of corn on College loam requires about 552 pounds of water; of wheat about 1000 pounds; of sugar beets, 630 pounds; of peas over 1100 pounds. Similar differences, though not quite so large, are found also in the column dealing with the pounds of water actually transpired for one pound of dry matter. In an arid region where water is the limiting factor, a large amount of work should be done on this and related subjects.

THE WATER EQUIVALENTS OF DRY MATTER.

The experiments conducted in Germany chiefly by Helriegel and in Wisconsin by King indicate that from 300 to 500 pounds of water are required under the climatic conditions there prevailing for the production of one pound of dry matter. Students of the far West were long since led to believe that such numbers are too small for arid conditions. It has long been a well established fact that not only evaporation, but transpiration varies with the average temperature, the sunshine and the relative humidity. Under arid conditions the temperature and the sunshine are high and the relative humidity is low. All this favors rapid evaporation and transpiration. True, plants growing under arid conditions so adapt themselves in the course of time to the prevailing conditions that they use much less water than formerly, perhaps less than plants that have been adapted to humid conditions. Under conditions of irrigation, however, usually wasteful, there is no need for the plant to economize in the use of water, and under such conditions in fact, the water cost of dry matter is usually higher than in many humid sections.

Certain experiments conducted at the Station upwards of ten years ago, led the investigators to declare that perhaps 750 pounds of water for each pound of dry matter would be a somewhat nearer approximation to the truth than the numbers obtained in Germany and Wisconsin. Table No. 37, which exhibits in a summary way the results obtained in the pot experiments, indicates that for wheat, even on fertile soils, this suggestion was not far from the truth. On College loam and Sanpete clay, it required 1017 and 1078 pounds respectively to produce one pound of dry matter. It must of course be remembered that the conditions under which these crops were produced were wasteful of water and that, therefore, under ordinary methods the amounts would probably have been reduced considerably. Even for corn, however, the factors on the infertile soils are more than twice the suggested 750 pounds, and on the fertile soils about 600 pounds. While this table does not enable us to say definitely how many pounds of water are required for the production of a definite amount of dry matter, yet it bears out the earlier teaching that transpiration and evaporation in an arid country are considerably larger than in a humid country; and that water conserving methods are, therefore, doubly important in an arid country. The high fertility of arid soils is probably the factor which offsets the high rate of evaporation and transpiration.

It is interesting to note that corn, which long has been known as the crop which can endure desert conditions better than most other agricultural plants, requires the fewest number of pounds of water, both total and for transpiration, for each pound of dry matter produced. Peas and even wheat are very much higher in their water needs. Investigations later to be published, dealing with crops grown under field conditions, will throw still further light upon the water equivalent of dry matter in an arid country.

THE VALUE OF SUMMER FALLOWING.

The value of summer fallowing, especially in dry farming, has been much discussed in recent years. The doctrine that summer fallowing enables the soil to store the precipitation of two seasons for the use of one crop has been supported by the investigations reported in Bulletin 104 of this Station; but several recent experimenters have questioned whether the increased soil moisture is an important factor in the production of crops and have suggested that a proper rotation might perhaps take the place of the fallow. This doubt has arisen be-cause it has been observed that when wheat or a similar crop is followed by a hoed crop, a fairly good yield of wheat may be obtained the following year.

The investigations reported in this bulletin explain the value of fallowing. Perhaps the most important result of these experiments is the fairly conclusive evidence that the amount of water actually required for the production of a pound of dry matter becomes smaller as the available fertility of the soil increases. This law is not new, but it does not seem to have been applied to the cultural methods in a country where the limiting factor is the water supply.

In England, during the dry season of 1870, it was observed that the hay plots that had been well fertilized produced nearly ten times as much dry matter as did the unfertilized plots, and that the increased yield could not be explained without assuming that dry matter had been produced with less water than ordinarily required. (a). In Germany, about 1876, it was determined that the transpiration of plants in water cultures varied with the solutions employed. When a mixture of all the necessary plant foods was used, the transpiration was least (b). More recently, in 1894, it was again observed that the amount of water transpired per gram of dry oats diminished as a more plentiful supply of plant nutrients were offered (c) and in 1898 an experiment was reported which showed that on an infertile soil 1190 grams of water were transpired for each gram of dry matter as against 550 grams on a very fertile soil (d). In 1908, investigators in the Bureau of Soils hit upon the same law (e). Scattered throughout agricultural literature are numerous observations to the effect that during seasons of drouth the crops on fertile soils suffer least. All these statements are in support of the findings of the experiments herein reported, that the amount of water used by plants diminishes as the fertility increases.

(a) Lawes and Gilbert, Centralblatt f. Agrikulturchemie, V. 2 Band p. 340. (b) Sachs, Burgerstein, From Sachsse, Lehrbuch der Agrikulturchemie, p. 416; also, Pfeffer's Plant Physiology, Vol. 1, p. 249. (c) Heinrich, abstract, Exp. Sta. Record, VII, p. 464. (d) Pagnoul, abstract, Exp. Sta. Record, XI, p. 118. (e) Gardner, Bull. 48, U. S. D. A. Bureau of Soils, pp. 54-56.

It has been shown in this bulletin, first, that thorough hoeing or cultivation throughout one season increases materially the yield of dry matter and decreases the amount of water required for each pound of dry matter produced; secondly, that resting the soil for several years has the same effect, and thirdly, that on infertile soils the water requirements of crops can be materially lowered by the addition of manure or commercial fertilizers. In every case the result is largely to be explained by the plant foods set free by the hoeing or fallowing or that added in the fertilizers.

The practical conclusion of all this is simply, that in districts where the rainfall is the chief consideration, it is not sufficient alone to store an abundance of water in the soil; but the soils themselves must be kept in such a condition that plants growing on them can produce dry matter with the smallest possible amount of water. Under a system of dry farm rotation in which a hoed crop is grown, perhaps every other year, in alternation with wheat, a fairly large amount of available plant food will be maintained, but at the same time the amount of stored moisture will be so near the danger limit as to jeopardize seriously the maturing crop. On the other hand, where the soil after being fall plowed and left in the rough throughout the winter is allowed to lie fallow the following summer a much larger amount of plant food is set free and at the same time a larger amount of water is stored in the soil. This combination of favorable conditions is much more likely to result in a profitable yield than can any system of culture which tends to weaken one of the other of these vitally important factors. In the Great Basin district, practical experience has demonstrated almost beyond a doubt that summer fallowing is indispensible in successful dry farming. In fact, it has become a doctrine that if land, at all adapted to dry farming, is summer fallowed every other year, a crop failure for want of water is impossible.

Dry farming lands are fallowed, first, to store in the soil the precipitation of two or more years, and, secondly, to set free plant food which will enable the crops to reach maturity with the smallest amount of water. This doctrine explains, undoubtedly, many of the successes and failures on dry farms. Numerous cases are on record where soils under a comparatively abundant rainfall failed to yield well, while other soils under a much smaller rainfall yielded abundantly. There are many soils, the available fertility of which is so low that they must be carefully cultivated in order to set free sufficient plant food before successful dry farming can be practiced upon them. This is shown in lands that are allowed to lie fallow for a year after the first plowing before crops are planted. The extraordinary yields sometimes obtained on soils where the rainfall is 12 inches or less may be explained by the naturally large quantity of available plant food found in them.

The understanding of the relationship between soil fertility and transpiration is vital to dry farming, but it is also important to irrigation farming, especially in districts where the water supply is limited. If the irrigation farmer, either by fallowing or by proper manuring, maintains his land in a fertile condition, he will better meet seasons of drouth or water shortage than his neighbor whose lands are in an unfertile condition. The principle here discussed must be incorporated into the practice of agriculture in arid regions.

SUMMARY.

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1. Cultivation, or hoeing, reduced largely the evaporation of water from bare soils.

2. Cultivation increased, generally, the yield of dry matter.

3. Cultivation diminished largely the amount of water transpired for one pound of dry matter.

4. Cultivation is much more effective on clay and sand soils than on ordinary loam soils.

5. Shading diminished greatly the evaporation from bare soils.

6. More water evaporates from bare soils under surface irrigation than under sub-irrigation or when the water stands near the surface.

7. In the majority of cases, surface irrigation gave the largest yields of dry matter; subirrigation nearly as much and standing water the smallest yields.

8. Approximately the same number of pounds of water are required to produce a pound of dry matter under conditions of subirrigation and standing water; a somewhat larger number is required under conditions of surface irrigation.

9. In all probability, the number of pounds of water actually transpired for the production of a pound of dry matter is the same under the various methods of irrigation.

10. Subirrigation is most satisfactory on loam soils.

11. The evaporation of water from bare soils increased with the increased saturation of the soil. The increase in the loss was usually much larger than the increase in saturation. Heavy irrigations should, therefore, be followed by immediate, careful and thorough cultivation.

12. Increasing the saturation of soils increased in a somewhat larger ratio the yields of dry matter.

13. Approximately the same number of pounds of water are required under various conditions of soil saturation for the production of one pound of dry matter.

14. The amount of water actually transpired for each pound of dry matter appears to be somewhat lower under conditions of high saturation.

15. On fertile soils heavy applications of water are not likely to be so wasteful as on infertile soils.

16. The yield of dry matter was much larger on soils that had rested during the preceding three years than on soils that had been cropped during the same period.

17. The number of pounds of water required for one pound of dry matter was much smaller on the soils that had been bare than on those that had been cropped during the preceding three years.

18. Fertile soils will produce crops with a smaller amount of water than will infertile soils.

19. The additions of fertilizers to infertile soils enables crops to produce dry matter at a lower water cost.

20. Soils vary greatly in their relationship to plants and water.

21. The seasons have a strong effect upon the yield of dry matter and upon the amount of water required for the production of one pound of dry matter.

22. The number of pounds of water required for the production of a pound of dry matter varies greatly with the crop, the soil, the season, the method of irrigation and the cultivation. In general, however, the amount of water required for the production of dry matter is very much higher in an arid region than in regions of abundant rainfall. The conservation of moisture is, therefore, of greater importance in the West than in the East.

23. Summer fallowing should be practiced on dry farms, first, to store the precipitation of two or more years for the use of one crop, and secondly, to set free an abundance of plant food which will enable crops to mature with less water.

ACKNOWLEDGMENTS.

I take great pleasure in acknowledging, gratefully, the valuable assistance and co-operation in carrying out the work recorded in this bulletin of my colleague, Professor L. A. Merrill, who was intimately associated with the work during the main period of its progress; and of the assistants who had immediate charge of the work, namely, Isaac C. Dunford (deceased), during the season of 1902; John T. Caine, III, during the season of 1903; William M. Jardine, during the season of 1904; Preston G. Peterson, during the season of 1905, and Ernest Carroll, during the season of 1908. The investigations were of such a nature that their successful completion depended largely upon the faithful work of the assistants who had the weighing and applications of water in immediate charge.

I tender my thanks, also, to Dr. E. D. Ball, Director of the Experiment Station, who helped to make possible the publication of these results which should have been published several years ago, and to Mr. Frank S. Harris, who rendered important help in the laborious computations.